

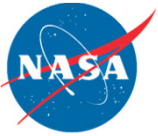
# End-to-End Data Flow on the Soil Moisture Active Passive (SMAP) mission

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The SMAP mission has not been formally approved by NASA. The decision to proceed with the mission will not occur until the completion of the National Environmental Policy Act (NEPA) process. Material in this document related to SMAP is for information purposes only.

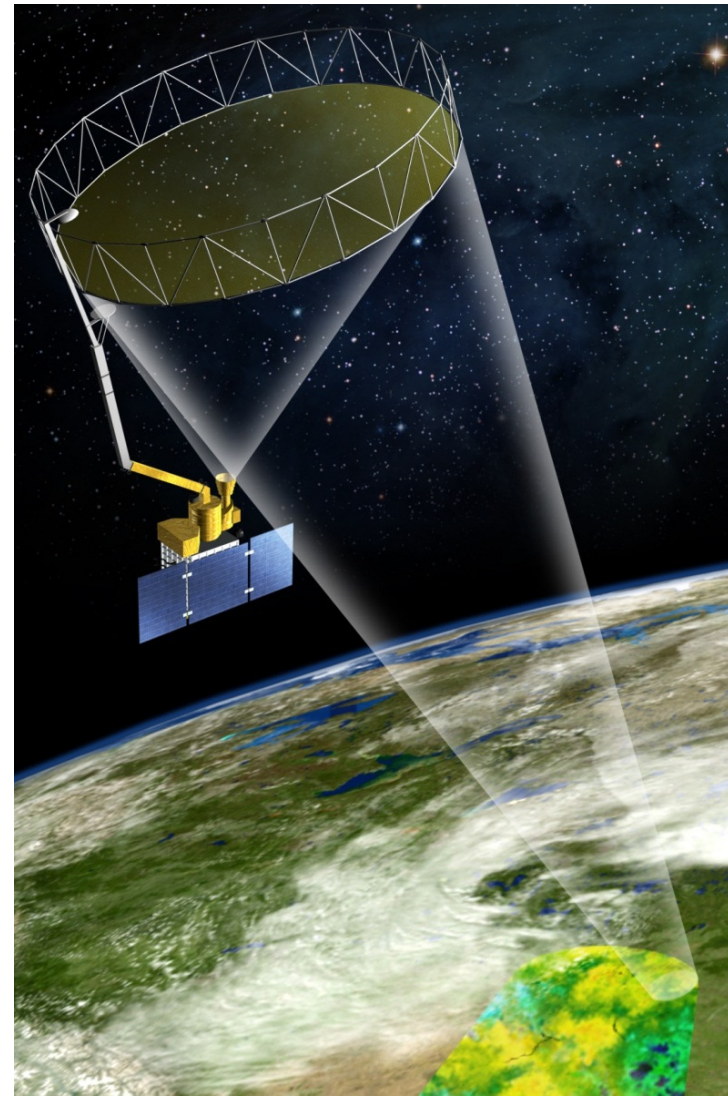




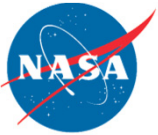
# Outline



- Introduction
  - Science Objective
  - Mission Overview
  - Observatory
- Data Loss Overview
- Instrument System Operation
- Interfaces
- Spacecraft System
- Ground System
- Summary





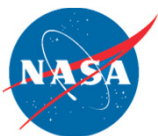


# Introduction: Science Objective

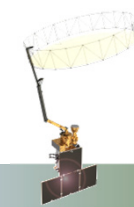


- Collect high-accuracy and high-resolution soil moisture and freeze/thaw measurements over Earth's land masses
- Data will be used to
  - Understand current and future water resources
  - Provide input to: climatology, hydrology, meteorology, ecology, and carbon cycle studies
  - Improve accuracy of weather and climate models
  - Aid in the prediction of natural disasters such as droughts and floods

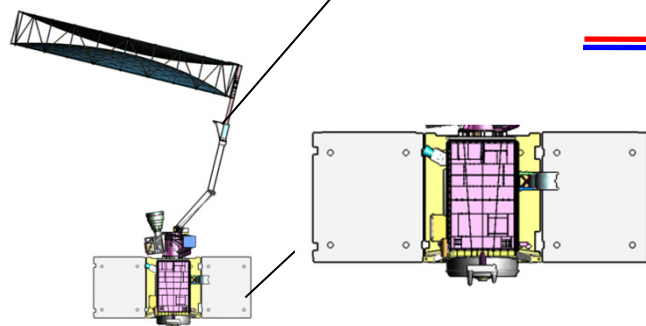




# Introduction: Mission Overview



SMAP  
Observatory  
(Deployed)



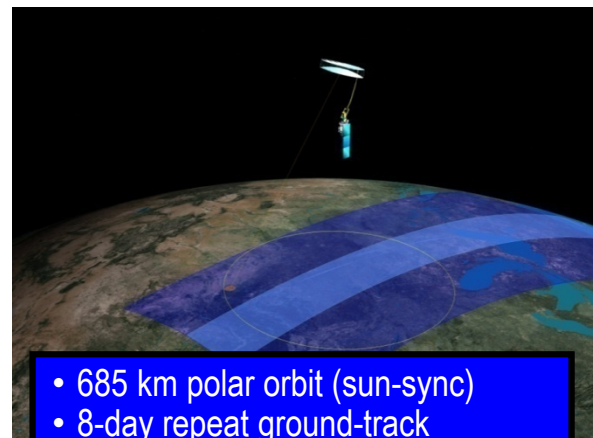
- Target Launch: 30 Nov. 2014

## Instrument

- L-band (1.26 GHz) Radar (JPL)
- L-band (1.41 GHz) Radiometer (GSFC)
- Shared Antenna (6m diameter)
- Spinning at 13 rpm

## Spacecraft

- JPL-developed & built
- JPL's Multi-mission System Architecture Platform for Avionics
- Commercial Space Components
- 3-axis Stabilized



- 685 km polar orbit (sun-sync)
- 8-day repeat ground-track
- Continuous instrument operation
- 3 day global coverage
- 3-year mission duration

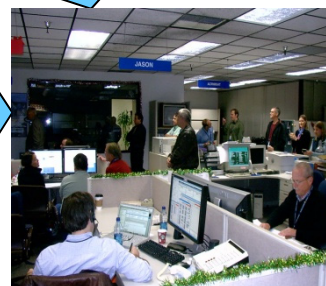
## Ground System

- Sends commands and uploads information to the S/C
- Receives science & engineering data from the S/C at 4 ground stations
- Sends data to the operations and processing center at JPL
- Processes the data into products, distributes the products to the users, and archives the data

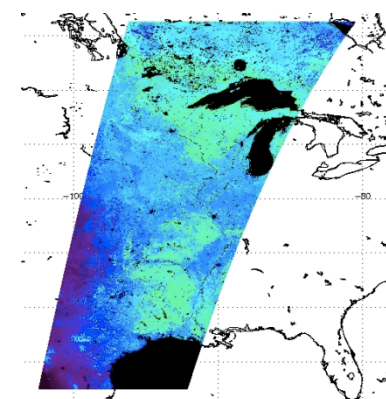
Near Earth Network  
(4 ground stations)



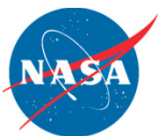
Surface  
Validation



SMAP Mission Operations  
Center & Science Data  
System (JPL)



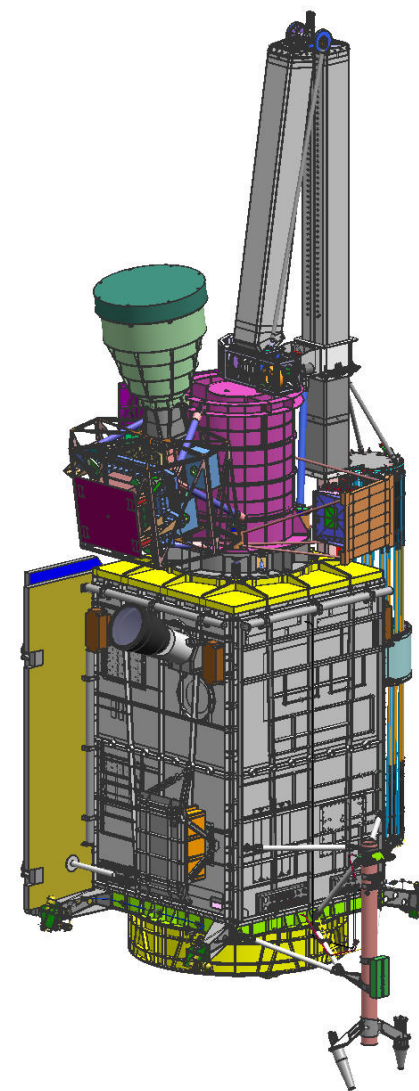
Science Data Products  
(JPL & GSFC)  
Soil Moisture & Freeze/Thaw State



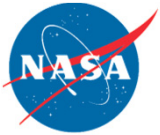
# Introduction: The Observatory



- The instrument is comprised of:
  - Integrated Control Electronics (ICE):
    - Controls rotation of the spun portion of the S/C
    - Provides a signal and power interface to the de-spun portion via slip rings
  - Radiometer (RAD):
    - On spun portion with ICE, thermal subsystem, and reflector
    - Position reduces losses and noise
  - Radar (SAR):
    - On de-spun portion; uses an RF rotary joint to send RF pulses
    - Position allows for less spun momentum and lower temperature
- The spacecraft includes:
  - Single-string Avionics
    - Command and Data Handling (CDH) and Flight Software (FSW)
  - S-band telecom and 130 Mbps science data return via X-band link
  - Passive and heater-based thermal control on de-spun side with bus structure serving as radiators
  - Deployable, fixed solar array
  - 3-axis-stabilized spacecraft providing momentum compensation for spinning antenna



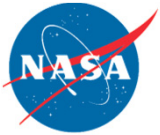
SMAP Launch Configuration



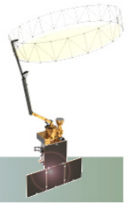
# Data Loss Overview



- Science team provides a science mask, which maps the regions where data should be acquired and at what resolution
- Contributions to the data loss budget:
  - Data that is lost due to issues with the operation of the observatory or the ground system
  - Data that is collected does not have high enough accuracy
- System must be designed to:
  - Reliably collect data
  - Preserve the data once acquired
- In order to meet science requirements, the observatory and the ground system combined are allocated a maximum of 12% science data loss.
- Data loss calculated from other mission experience (ground station outage, Aerospace study on satellite anomalies), planned outages (maneuvers, calibration), and Aquarius data
- Many causes of data loss, but most challenging: radio frequency interference (RFI) generated by other instruments that operate in the L-band on and near the Earth



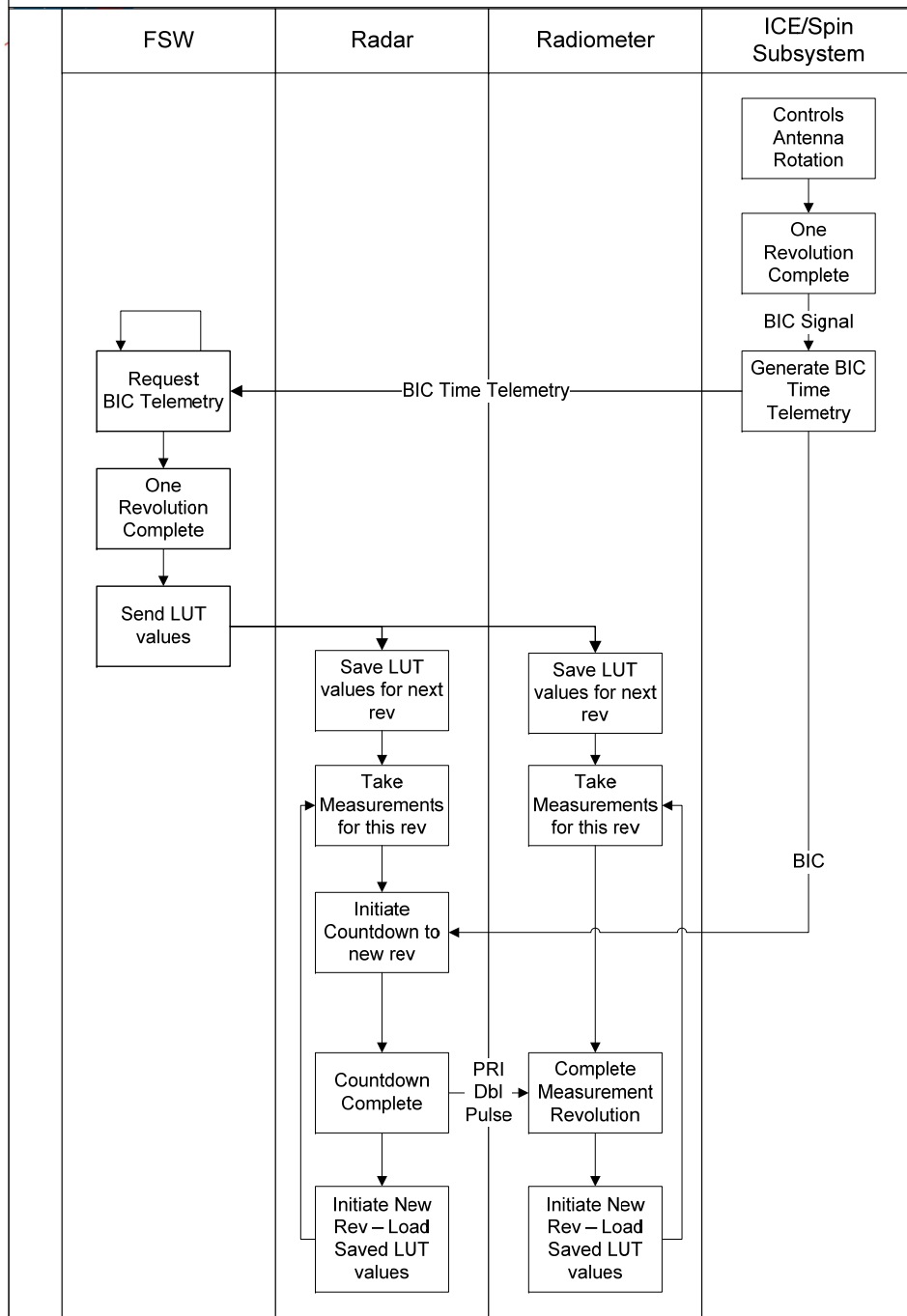
# Instrument System: Operation



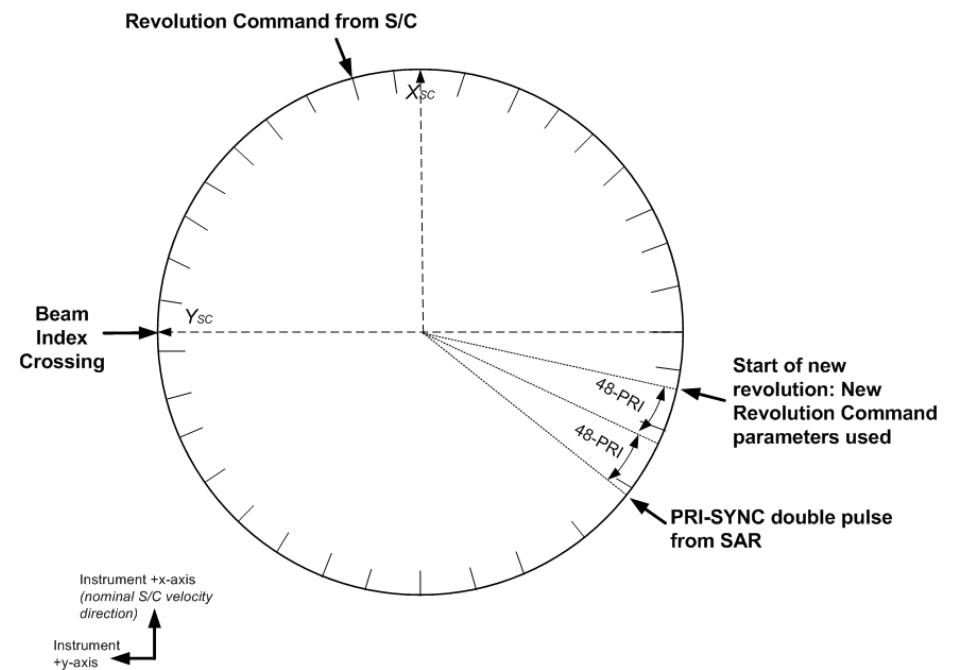
- SMAP's Instruments require specific operating parameters every revolution, which are all dependent on the location of the observatory
  - Radar: Time between pulses (PRI length), operating frequencies, when to collect high rate data, and the time between the Beam Index Crossing (BIC) and the start of the new revolution (double pulse to radar)
  - Radiometer: PRI length, when to collect high rate data
- These parameters are stored in a table of values called the Instrument Operation Lookup Table (LUT)
  - Flight Software (FSW) sends a command to the Radar and Radiometer every revolution with the appropriate LUT values
  - LUT is constructed as a surface projection of the eight day orbit based on time passage from a predefined initial point.
- LUT has margin for limited cross-track and along-track errors, but drag and other errors will make the actual orbital path drift from what is modeled in the LUT
  - Ground will calculate and send the FSW correction factors for the LUT approximately once a week
    - Capability to jump to a new LUT index
    - Change the wait time between indices in the LUT



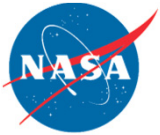
## SMAP's Unique Measurement Process



## System Timing



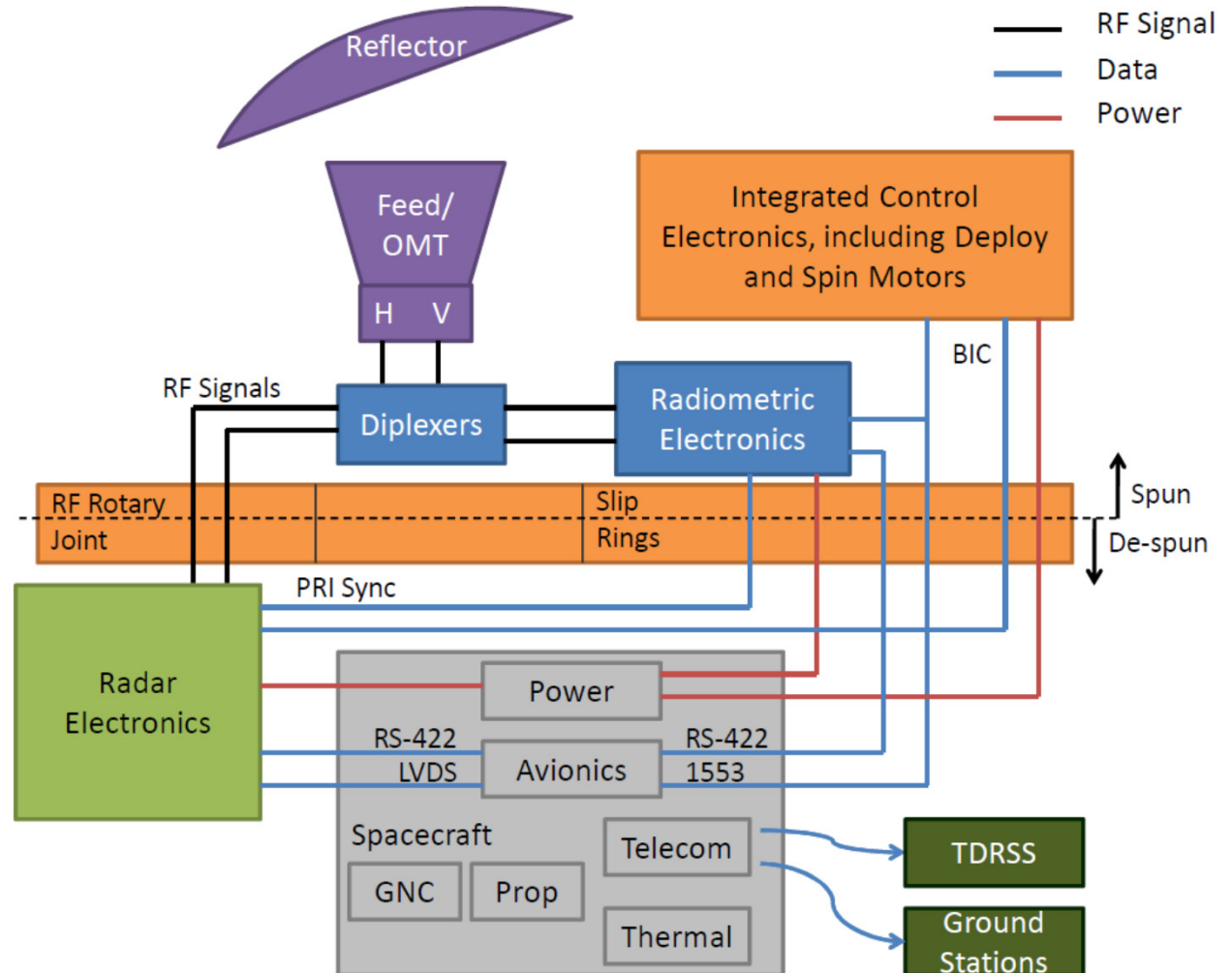


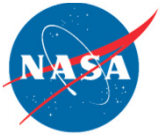


# Tight Interface Timing Reduces Data Loss

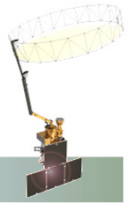


- Tightly timed interfaces keep the radar and radiometer in sync with the rotation of the antenna and limit data loss
  - PRI Sync: Signal to Radiometer that Radar is going to transmit
  - Beam Index Crossing (BIC): Signal to Radar (from ICE) to begin a countdown to the start of the next revolution
  - PRI Sync Double Pulse: At end of countdown, radar double pulses the PRI Sync to signal the Radiometer that it's the start of a new revolution
- Command and data interfaces (1553, RS-422, LVDS) are reliable and high heritage

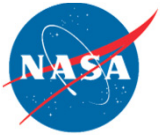




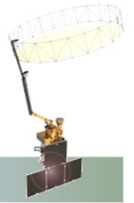
# Instrument RFI Mitigation



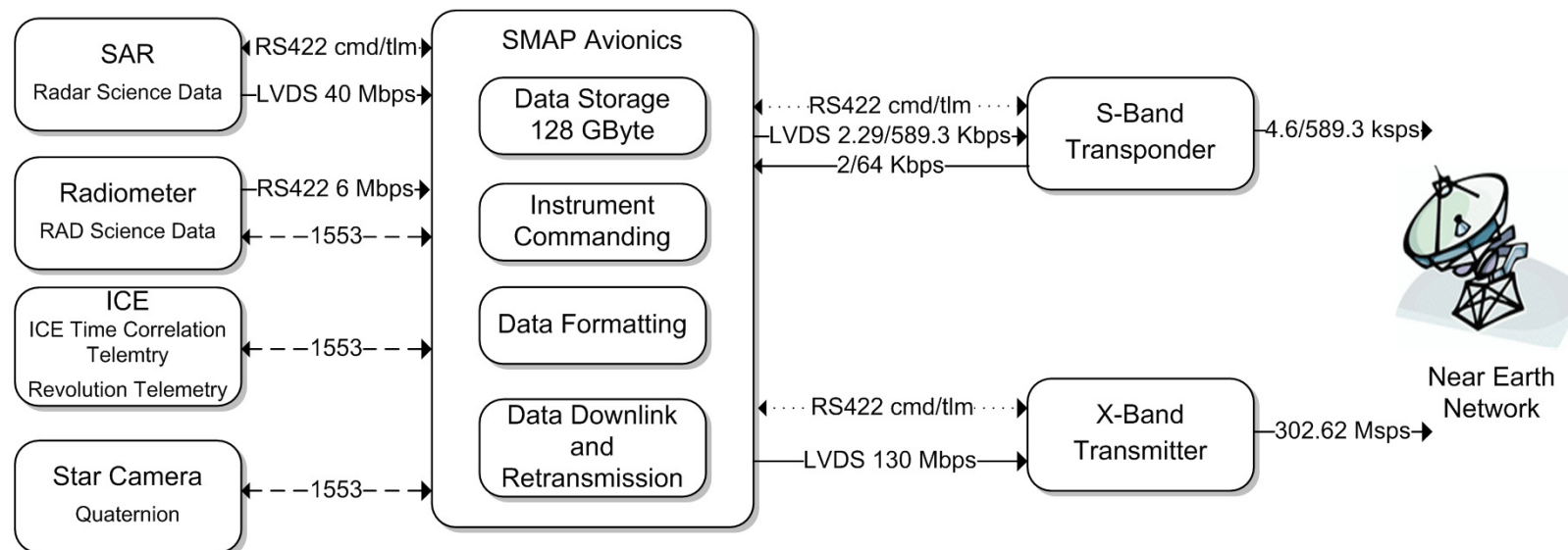
- SMAP is highly sensitive to RFI and has combined techniques from many sources to reduce its impact on the data
- Radar
  - Frequency hopping: Each antenna revolution is split into 16 segments, and each segment can operate in a different frequency
  - Global and Periodic RFI Surveys
    - During commissioning, radar will collect global information on RFI
    - Every five minutes during the mission, radar will collect RFI information for one antenna revolution
    - Radar frequencies can then be updated from RFI Survey information
- Radiometer
  - Operates in a protected spectral band, though can still be affected by out-of-band and spurious emissions from radars, communications systems, etc.
  - No active RFI prevention; ground responsible for identifying and filtering out RFI
  - Four methods for filtering out RFI data on the ground
    - Time domain signals larger than those from geophysical properties
    - Frequency domain signals larger than those from geophysical properties
    - A departure from Gaussian distribution of the data
    - Unusually large values of the third and fourth Stokes parameters

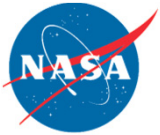


# Spacecraft System: Data Flow

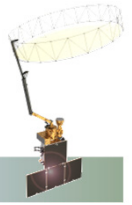


- Merges JPL Deep-Space heritage hardware and software with a high speed, high volume science data system
  - AVS augmented to accommodate speed and volume of science data
- Science Data Flow
  - Stored in non-volatile memory, in two logical partitions formatted as ring buffers
  - Transmitted to the ground via X-Band radio to the Near Earth Network
  - Basic prioritization of science downlink (radar vs. radiometer) and a simple retransmission function
- Engineering Data Flow
  - Due to lower speeds as well as the high heritage, data is parsed and saved in a Unix-like file system
  - Split into CCSDS File Delivery Protocol (CFDP) data protocol data units (DPDU) and then encapsulated in AOS frames
  - Transmitted to the ground via S-Band radio to the Near Earth Network
  - Downlink prioritization both on a per-file and a per-data type basis and retransmission available



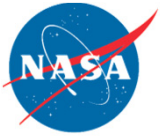


# Spacecraft System: Data Loss

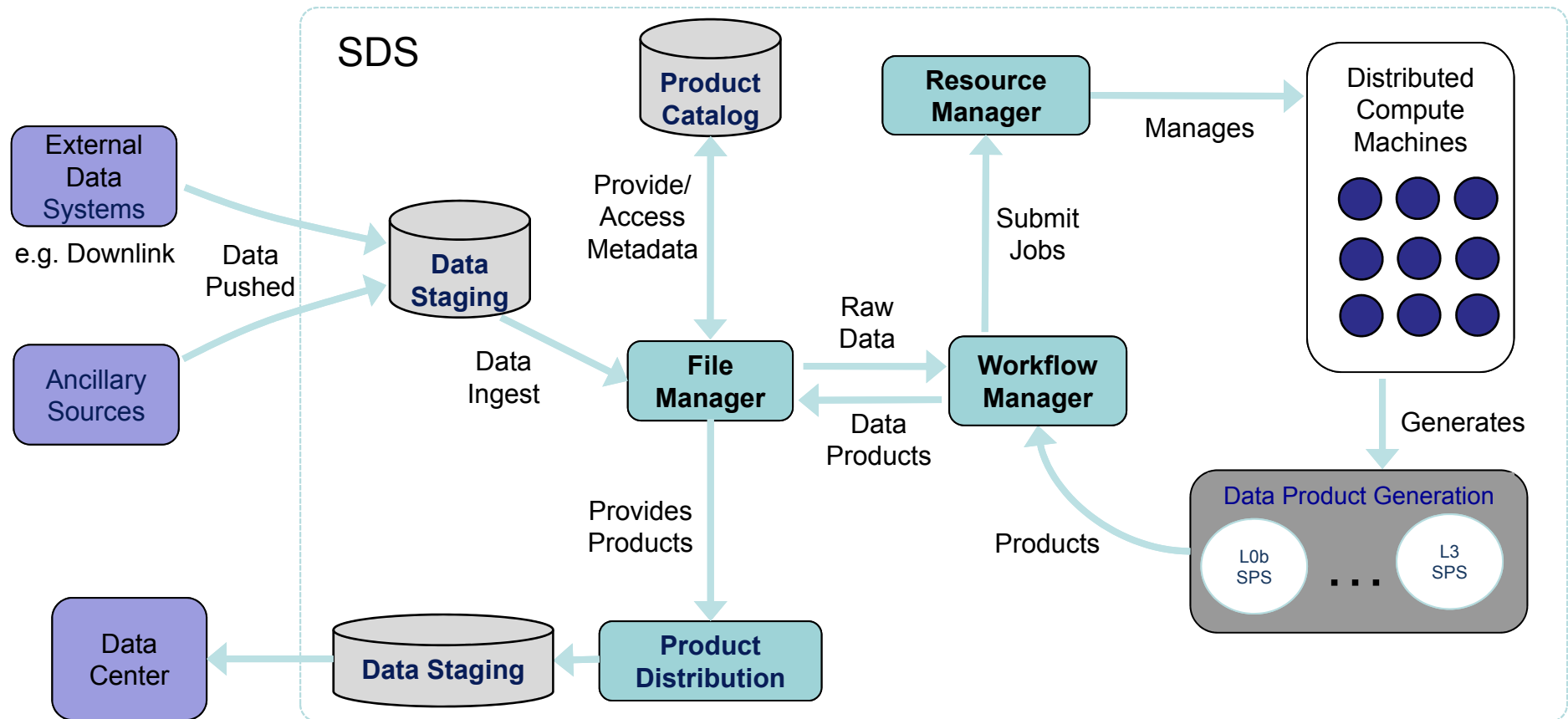
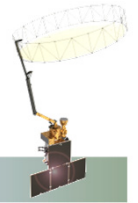


- Data Loss – two key factors
  - Reliability of multi-level cell (MLC) flash memory modules, used for science data storage
    - MLC allows high data storage capability with low resource impact
    - MLC is susceptible to error as number of program-erase cycles increases
    - Mitigation:
      - Spacecraft provides error detection and correction (EDAC) capability that will correct any single bit error
      - FSW will map around blocks of memory that have been identified as “bad” or “failed” during testing
      - Engineering model testing demonstrated the design meets the SMAP mission requirements even with program-erase cycle counts in excess of three times design life
  - Losses associated with errors in the downlink
    - SMAP requirements dictate that all return links provide an uncorrectable error rate of lower than  $1 \times 10^{-6}$ .
    - Mitigation:
      - Use both Reed Solomon and convolutional ( $7 \frac{1}{2}$ ) error correction encoding
      - Link design includes sufficient margin to handle unforeseen problems
        - Worst case return link conditions gives 3.6 dB margin (confirmed by NEN office)
      - Can select science data for retransmission

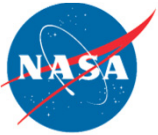




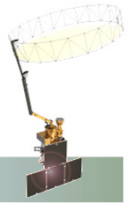
# Ground System: Automated Processing Meets Mission Latency Requirements



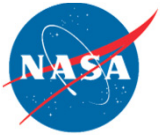
Product	Expected Latency Time	Required Latency
Level 1 (Separate radar and radiometer measurements)	12 hours	< 24 hours
Level 2 (Non-global soil composite soil moisture)	12 hours	< 24 hours
Level 3 (Daily Global Freeze/Thaw, Composite Soil Moisture)	50 hours	< 72 hours



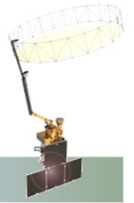
# Ground System: Data Loss



- Pre-Ground system:
  - On-board bit errors will be less than  $10^{-6}$
  - Data is stored with the minimum number of bits, which increases the likelihood of bit flips on key telemetry items
    - To mitigate this, key telemetry elements appear in more than 1 location in the science data stream
- Ground System:
  - Ground station reports gaps in transfer frame sequence, which is sent to Mission Operations Center within 15 minutes
  - First products are time-ordered, and software checks for time gaps
  - Software checks the rest of the products for data cells that are bad or non-existent
  - 22 hours of science data (and weeks of engineering telemetry) stored on-board, and a re-transmit can be requested

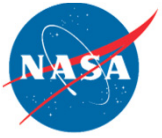


# Summary



- Each component of the system faces challenges in producing quality data
  - Instrument
    - Uses tight synchronization and well-proven interfaces
    - Uses multiple techniques to avoid RFI
  - Spacecraft
    - Provides error detection and correction capability and maps around bad memory
    - Able to re-transmit data
  - Ground
    - Automated systems look for missing data and process data quickly
    - Identifies, filters out, and adjusts data collection parameters to reduce the impact of RFI
- Through pre-planning mitigation methods and RFI mitigation and detection techniques, the SMAP mission will be able to limit data loss to 12% so that the science requirements can be met
- Future Work
  - Test and verify the interfaces
  - Use Aquarius data to improve estimates
  - Analyze spacecraft thermal stabilization after maneuvers

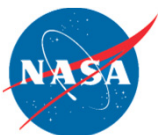
Component	Expected Data Loss
Instrument	6.6%
Spacecraft	1.4%
Ground System	4%
Overall	12%



# Backup







# Ground System: Products



- Time span between the instrument acquisition of the data and the time when the products are available to the users drives ground system design.
- ~8 GB per communication link (~15 per day) downlinked to the ground stations and sent to Science Data System (SDS, at JPL) within 1 hour
- All nominal processes (and some off-nominal processes) automated
- Required latency shown in table

Data Product Short Name	Description	Product Files Daily	Daily Volume (GBytes)	Latency after Acquisition
L1A_Radar	Parsed radar telemetry	29	75.436	24 hours
L1B_S0_LoRes	Low Resolution Radar $\sigma_0$ in Time Order	29	9.002	24 hours
L1C_S0_HiRes	High Resolution Radar $\sigma_0$ on Swath Grid	29	46.698	24 hours
L1A_Radiometer	Parsed radiometer telemetry	29	32.900	24 hours
L1B_TB	Radiometer $T_B$ in Time Order	29	1.628	24 hours
L1C_TB	Radiometer $T_B$	29	0.270	24 hours
L2_SM_A	Radar Soil Moisture	29	2.144	48 hours
L2_SM_P	Radiometer Soil Moisture	15	0.015	48 hours
L2_SM_AP	Active-Passive Soil Moisture	15	0.144	48 hours
L3_FT_A	Daily Global Composite Freeze/Thaw State	1	1.410	72 hours
L3_SM_A	Daily Global Composite Radar Soil Moisture	1	3.335	72 hours
L3_SM_P	Daily Global Composite Radiometer Soil Moisture	1	0.014	72 hours
L3_SM_AP	Daily Global Composite Active-Passive Soil Moisture	1	0.281	72 hours
L4_SM	Surface & Root Zone Soil Moisture	16	5.200	7 days
L4_C	Carbon Net Ecosystem Exchange	1	0.116	14 days